

TRANSMITTAL LETTER TO THE UNITED STATES
DESIGNATED/ELECTED OFFICE (DO/EO/US)
CONCERNING A FILING UNDER 35 U.S.C. 371

9847-0044-6X PCT

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR

09 / 508683

INTERNATIONAL APPLICATION NO.
PCT/SE98/01749INTERNATIONAL FILING DATE
29 SEPTEMBER 1998PRIORITY DATE CLAIMED
30 SEPTEMBER 1997TITLE OF INVENTION
POWER TRANSFORMER/REACTOR AND A METHOD OF ADAPTING A HIGH VOLTAGE CABLEAPPLICANT(S) FOR DO/EO/US
Li MING, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
- a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
- b. ☒ has been transmitted by the International Bureau.
- c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
- a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
- b. ☐ have been transmitted by the International Bureau.
- c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
- d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
- A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report
Notice of Priority
Marked-up Copy of Specification
Form PTO-1449
Response to Petition Under 37 CFR 1.182

U.S. APPLICATION NO. 09/508683	INTERNATIONAL APPLICATION NO. PCT/SE98/01749	ATTORNEY'S DOCKET NUMBER 9847-0044-6X PCT
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20. The following fees are submitted:

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):

- | | |
|--|----------|
| <input type="checkbox"/> Search Report has been prepared by the EPO or JPO | \$840.00 |
| <input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) | \$670.00 |
| <input type="checkbox"/> No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) | \$760.00 |
| <input checked="" type="checkbox"/> Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO | \$970.00 |
| <input type="checkbox"/> International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) | \$96.00 |

ENTER APPROPRIATE BASIC FEE AMOUNT =

\$970.00

Surcharge of \$130.00 for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).

\$130.00

CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE
Total claims	28 - 20 =	8	x \$18.00
Independent claims	3 - 3 =	0	x \$78.00

\$0.00

Multiple Dependent Claims (check if applicable) ☐

\$0.00

TOTAL OF ABOVE CALCULATIONS = \$1,244.00

Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) (check if applicable). ☐

\$0.00

SUBTOTAL = \$1,244.00

Processing fee of \$130.00 for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)).

\$0.00

TOTAL NATIONAL FEE = \$1,244.00

Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) (check if applicable). ☐

\$0.00

TOTAL FEES ENCLOSED = \$1,244.00

Amount to be refunded	\$
charged	\$

☒ A check in the amount of \$1,244.00 to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. _____ in the amount of _____ to cover the above fees.
A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. 15-0030 A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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REGISTRATION NUMBER

March 28, 2000
DATE

09/508683

416 Rec'd PCT/PTO 28 MAR 2000

9847-0044-6X PCT
ENKEL 8303

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF :
Li MING ET AL : ATTN: APPLICATION DIVISION
SERIAL NO: NEW PCT APPLICATION :
(Based on PCT NUMBER SE/98/01749)
FILED: HEREWITH :
FOR: POWER TRANSFORMER/REACTOR:
AND A METHOD OF ADAPTING
A HIGH VOLTAGE CABLE

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Prior to examination on the merits, please amend the above-identified patent applications as follows:

IN THE CLAIMS

Please cancel without prejudice or disclaimer, Claims 1-27.

Please add new Claims 28-55 as follows:

--28. A power transformer/reactor comprising:
a plurality of windings, each for carrying different phases, each winding made from a high voltage cable having
an electric conductor,
a first semiconducting layer disposed around the conductor,
a first insulating layer disposed around the first semiconducting layer, and

a second semiconducting layer disposed around the first insulating layer,
wherein

the second semiconducting layer being directly earthed at n points along said winding, n being an integral number, and $n \geq 2$,

two of said n points being at ends of each winding,

an electric contact being interrupted in the second semiconducting layer at $2(n-1)$ different interruptions between respective ends in each winding, and each of the interruptions for each winding being earthed by cross-connection.

29. A power transformer/reactor according to claim 28, wherein:

at least one point of said n points between both ends being indirectly earthed.

30. A power transformer/reactor according to claim 28, wherein:

at each interruption in the second semiconducting layer there is arranged a third semiconducting layer configured to reduce an amplification an electric field strength at the interruption.

31. A power transformer/reactor according to claim 30, wherein:

interruptions in the electric contact in the second semiconducting layers of the windings being due to an absence of a portion of the second semiconducting layer around a periphery of the high voltage cable down to the first insulating layer so that grooves surrounded by the second semiconducting layer are present.

32. A power transformer/reactor according to claim 31, wherein:

the second insulating layer being arranged onto respective of the grooves, beside each groove the second insulating layer covering a part of the second semiconducting layer on both sides of each groove,

a third semiconducting layer being disposed at the second insulating layer so that one end of the third semiconducting layer covers one edge of the second insulating layer and has electric contact to the second semiconducting layer, and that the other end of the third semiconducting layer does not cover the other edge of the second insulating layer but extends along part of the second semiconducting layer located under the second insulating layer.

33. A power transformer/reactor according to claim 32, wherein:
the edges of the second semiconducting layer at said grooves slope such that the grooves have a least width at the first insulating layer.

34. A power transformer/reactor according to claim 33, wherein:
the third semiconducting layer at the end covering the edge of the second insulating layer makes mechanical contact with the second semiconducting layer, and the other end of the third semiconducting layer does not make mechanical or electric contact with the second semiconducting layer.

35. A power transformer/reactor according claim 28, wherein:
a conductor area of the conductor of the high voltage cable being in an inclusive range of 80 through 3000 mm²; and
an outer cable diameter being in an inclusive range of 20 through 250 mm.

36. A power transformer/reactor according to claim 28, wherein:
two of the interruptions are positioned between two consecutive direct earthing points.

37. A power transformer/reactor according to claim 28, wherein:
each cross-connected earthing is formed by the second semiconducting layers of the different windings at each interruption being connected to one another and indirectly earthed.

38. A power transformer/reactor according to claim 37, wherein:
2(n-1) interruptions are formed per winding and thus 3(n-1) connected sections of the second semiconducting layer per winding, and
at an interruption q, where $1 \leq q \leq 2(n-1)$, of a different winding section r, where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer of one winding is connected to section (r+1) of the second semiconducting layer of a consecutive winding, and that section r of the second semiconducting layer of the first winding is connected to section r of the second semiconducting layer of remaining windings, and that section r of the second semiconducting layer of a last winding and section (r+1) of the second semiconducting layer of the first

winding are connected to the indirect earthing, except when r is evenly divisible by 3 and for the last section, where $r=3(n-1)$.

39. A power transformer/reactor according to claim 28, wherein:
each direct earthing is performed by a galvanic connection to earth.

40. A power transformer/reactor according to claim 28, wherein:
each indirect earthing is performed by a capacitor connected between the second semiconducting layer and earth.

41. A power transformer/reactor according to claim 28, wherein:
the indirect earthing is performed by an element connected between the second semiconducting layer and earth, having a non-linear voltage-current characteristic.

42. A power transformer/reactor according to claim 28, wherein:
the indirect earthing is performed by a circuit element connected between the second semiconducting layer and earth, said circuit element having a non-linear voltage-current characteristic connected in parallel with a capacitor.

43. A power transformer/reactor according to claim 42, wherein:
the indirect earthing being performed by at least one of the circuit element, another element connected between the second semiconducting layer and earth, having a non-linear voltage-current characteristic, and a capacitor connected between the second semiconducting layer and earth.

44. A power transformer/reactor according to claim 42, wherein:
the element includes at least one of a spark gap, a gas-filled gas diode, a zener-diode and a varistor.

45. A power transformer/reactor according to claim 28, further comprising:
a magnetizable core.

46. A power transformer/reactor according to claim 28, wherein the power transformer/reactor does not include a magnetizable core.

47. A power transformer/reactor according to claim 28, wherein:

said first semiconducting layer and said insulating layer, and said insulating layer and said second semiconducting layer being arranged to adhere to one another even when the cable is bent.

48. A method for adjusting a high voltage cable for windings in a power transformer/reactor which high voltage cable comprises an electric conductor, around which there is arranged a first semiconducting layer, around the first semiconducting layer there is arranged a first insulating layer, and around the first insulating layer there is arranged a second semiconducting layer, comprising steps of:

connecting directly to earth the second semiconducting layer at n points of each winding, where n is an integral number, and two of said n points are arranged at both ends of each winding;

forming two interruptions between each pair of directly earthed points in electric contact in the second semiconducting layer; and

cross-connecting the second semiconducting layer of the windings at each interruption.

49. A method according to claim 48, further comprising:

indirectly earthing at least one point in each winding between both ends of the second semiconducting layer.

50. A method according to claim 48, further comprising:

applying a third semiconducting layer at each said interruption in the second semiconducting layer in order to reduce an amplification of electric field strength at each interruption.

51. A method according to claim 48, wherein:

said forming step includes removing the second semiconducting layer around a periphery of the high voltage cable down to the first insulating layer so as to form grooves surrounded by the second semiconducting layer.

52. A method according to claim 51, wherein:

said applying step includes

applying a second insulating layer over each groove in such a way that part of the second semiconducting layer is on both sides of each groove is additionally covered; and

applying a third semiconducting layer on the second insulating layer in such a way that the one end of the third semiconducting layer covers one edge of the second insulating layer and has electric contact to the second semiconducting layer, and the other end of the third semiconducting layer does not cover the other edge of the second insulating layer but extends along a part of the second semiconducting layer located under the second insulating layer.

53. A method according to claim 48, wherein said cross-connecting step includes:

connecting the second semiconducting layer of each winding at each interruption and indirectly earthing each interruption.

54. A method according to claim 53, wherein said cross-connecting step includes the following steps to achieve 2 (n-1) interruptions per winding and 3(n-1) connected sections of the second semiconducting layer per winding:

connect at an interruption q, where $1 \leq q \leq 2(n-1)$, of the different windings, section r, where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer of one winding to section (r+1) of the second semiconducting layer of a consecutive winding;

connecting section r of the second semiconducting layer of the first winding to section r of the second semiconducting layer of remaining windings; and

connecting section r of the second semiconducting layer of a last winding and section (r+1) of the second semiconducting layer of the first winding to an indirect earthing node, where r is evenly divisible by 3, except for the last section where $r=3(n-1)$.

55. A mechanism for adjusting a high voltage cable for windings in a power transformer/reactor, comprising:

the high voltage cable, which includes

an electric conductor,

a first semiconducting layer disposed around the electric conductor,

a first insulating layer disposed around the first semiconducting layer, and

a second semiconducting layer disposed around the first insulating layer;

means for connecting directly to earth the second semiconducting layer at n points of each winding, where n is an integral number, and two of said n points are arranged at both ends of each winding;

means for forming two interruptions between each pair of directly earthed points in electric contact in the second semiconducting layer; and

means for cross-connecting the second semiconducting layer of the windings at each interruption.--

IN THE ABSTRACT OF THE DISCLOSURE

After the last page, please insert the following Abstract of the Disclosure.

--ABSTRACT OF THE DISCLOSURE

A power transformer/reactor having at least one winding manufactured with a high-voltage cable made of a conductor, a first semiconducting layer around the conductor, an insulating layer around the first semiconducting layer, and a second semiconducting layer around the insulating layer. The second semiconducting layer is directly earthed at n points of the winding, wherein n is an integral number greater than 1, and two of the n points being at ends of the windings. An electric contact being interrupted $2(n-1)$ times between both ends the second semiconducting layer. At each interruption the second semiconducting layer and third semiconducting layer combine to reduce an electric field. The interruptions of separate windings being cross-connected and earthed, but at least one point between both ends being indirectly earthed.--

REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested.

Claims 28-55 are pending, Claims 1-27 having been cancelled without prejudice or disclaimer and Claims 28-55 having been added by way of the present amendment. New Claims 28-55 find support in original Claims 1-27 and thus no new matter is added. An abstract has been added consistent with U.S. patent drafting procedure.

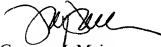
Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a substitute specification is filed herewith in addition to a marked-up copy of the original application. Please enter this substitute specification. To the extent any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes could be construed as typographical errors and the language is included in the originally filed PCT specification should be construed as containing the controlling language.

The present document is one of a set of patent applications containing related technology as was discussed in "Response to Petition Under 37 C.F.R. §1.182 seeking special treatment relating to an electronic search tool, and decision on Petition Under 37 C.F.R. §1.143 seeking waiver of requirements under 37 C.F.R. §1.98", filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an information disclosure statement is filed herewith including a 1449 form with references that are included as part of the specially created official digest in Class 174. It is believed that submission of these materials and the reference to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with a decision.

In view of the present amendment, and in light of the foregoing comments, an examination on the merits is believed to be in order and an early and favorable action is respectfully requested.

Respectfully submitted,

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SUBSTITUTE SPECIFICATION

9847-0044-6X PCT
ENKEL 8303

TITLE OF THE INVENTION

POWER TRANSFORMER/REACTOR AND A METHOD
OF ADAPTING A HIGH VOLTAGE CABLE

BACKGROUND OF THE INVENTIONField of the Invention

The present invention relates in a first aspect to a power transformer/reactor. A second aspect of the present invention relates to a method of adapting a high voltage cable for windings of a power transformer/reactor

Discussion of the Background

For all transmission and distribution of electric energy, transformers are used and their task is to allow exchange of electric energy between two or more electric systems having generally different voltage levels. Transformers are available in all power ranges from the VA up to the 1000 MVA range. With respect to the voltage range, there is a spectrum up to the highest transmission voltages which are being used today. Electromagnetic induction is used for the transmission of energy between electric systems.

For the transmission of electric energy, reactors are also included as an essential component, for example for phase compensation and filtering.

The transformer/reactor relating to the present invention belongs to the so-called power transformers/reactors with a rated output ranging from a few hundred kVA up to more than 1000 MVA with a rated voltage ranging from 34 kV and up to very high transmission voltages.

From a purely general point of view, the primary task of a power transformer is to allow exchange of electric energy between two or more electrical systems usually having different voltages with the same frequency.

A conventional power transformer/reactor comprises a transformer core referred to below as core, made of laminated preferably oriented sheets, usually of silicon steel. The

core is made of a number of core legs connected by yokes. Around the core legs there are a number of windings which are normally referred to as primary, secondary and regulation winding. As far as power transformers are concerned these windings are practically always concentrically arranged and distributed along the length of the core legs.

Other types of core constructions occasionally occur such as those of the so-called shell-type transformer or the toroidal-type transformer. Examples relating to core constructions are described in for example DE 40414. The core may be made of conventional magnetizable material such as said oriented steel sheet, and of other magnetizable material such as ferrites, amorphous material, wire strands or metal tape. With respect to reactors, the magnetizable core is as known not necessary.

The above-mentioned windings constitute one or several coils connected in series, which coils are constructed of a number of turns connected in series. The turns of a single coil normally make up a geometrically continuous unit which is physically separated from the remaining coils.

The insulation system, partly on the inside of a coil/winding and partly between coils/windings and other metal parts is normally in the form of a solid cellulose or varnish based insulation closest to the separate conducting element and the insulation on the outside is in the form of a solid cellulose insulation, a fluid insulation and possibly an insulation in the form of a gas. Windings having insulation and possible bulky parts represent in this way large volumes that will be subjected to high electric field strengths occurring in and around the active electro-magnetic parts belonging to transformers. A detailed knowledge of the properties of insulation material is required in order to predetermine the dielectric field strengths which arise and in order to attain a dimensioning such that there is a minimal risk of electric breakdown. Furthermore it is important to achieve a surrounding environment which does not change or lead to the deterioration of the insulation properties.

Today's predominant outer insulation system for conventional high voltage power transformers/reactors consists of cellulose material for the solid insulation and transformer oil for the fluid insulation. Transformer oil is based on so-called mineral oil.

Additionally, a conventional insulation is relatively complicated to construct and special measures need to be taken during manufacture in order to utilize the good insulation properties of the insulation system. The system should have a low moisture content, the solid phase in the insulation system needs to be well impregnated with the surrounding liquid, the

10 risk for remaining gas pockets in the solid phase must be minimal. During manufacture a special drying process is carried out on the complete core with windings before it is lowered into the tank. After lowering the core and sealing the tank, the latter is emptied of all air by means of a special vacuum treatment before being filled with oil. This process is relatively
5 time consuming seen from the entire manufacturing process in addition to requiring the extensive utilization of resources in the workshop.

The tank surrounding the transformer must be constructed in such a way that is able to withstand full vacuum since the process requires that all the gas be pumped out to almost absolute vacuum which involves extra material consumption and manufacturing time.

15 Furthermore, the installation on site requires renewed vacuum treatment, a process to be repeated each time the transformer is opened for attention or for inspection.

SUMMARY OF THE INVENTION

20 The power transformer/reactor, according to the present invention, includes at least one winding arranged in most cases around a magnetizable core which is of varying geometry. The term "windings" will preferably be referred to below in order to simplify the following specification. The windings are formed of a high voltage cable having solid insulation. The cables are made of at least one centrally located electric conductor around which there is arranged a first semiconducting layer, around the first semiconducting layer there is arranged a solid first insulating layer and around the insulating layer there is arranged
25 a second outer semiconducting layer.

An additional advantage is that the layers are arranged to adhere to one another even when the cable is bent. Hereby, good contact is achieved between the layers during the cable's entire life.

30 The second semiconducting layer is directly earthed at n points of each winding, where n is an integral number and $n \geq 2$, and whereby two of the directly earthed points are arranged at or in the vicinity of both ends of each winding. The electric contact is interrupted $2(n-1)$ times in the second semiconducting layer. The second semiconducting layer of different phases at each interruption is earthed in a cross-connected manner.

A method for adapting a high voltage cable for windings of a power
35 transformer/reactor, according to the present invention, comprises the following steps:

- directly earthing the second semiconducting layer at n points of each winding

where n is an integral number and $n \geq 2$, and whereby two of the points are arranged at or in the vicinity of both ends of each winding;

- achieving two interruptions in the electric contact in the second semiconducting layer between each pair of directly earthed points; and
- earthing in a cross-connected manner the second semiconducting layer at different phases of each interruption.

The use of such a cable implies that those areas of the transformer/reactor which are subjected to high electric field stress are limited to the solid insulation of the cable. Remaining parts of the transformer/reactor, with respect to high voltage application, are only subjected to very moderate electric field strengths. Furthermore, the use of such a cable eliminates several problematic areas described in the background of the invention. Consequently a tank is not needed for the insulating and cooling medium. Besides, the insulation also becomes substantially simple. Construction time is considerably shorter compared to that of a conventional power transformer/reactor. The windings may be manufactured separately and the power transformer/reactor may be assembled on site.

However, the use of such a cable presents new problems which must be solved. The outer semiconducting layer must be directly earthed at or in the vicinity of both ends of the cable so that the electric stress, which arises both at normal operating voltage and during transience, will primarily only load the solid insulation of the cable. The semiconducting layer in addition to these direct earthings form a closed circuit in which a current is induced during operation. The resistivity of the layer must be great enough so that the resistive losses arising in the layer are negligible.

Besides this magnetically induced current, a capacitive current will flow into the layer through the direct earthing in both ends of the cable. If the resistivity of the layer is too great, the capacitive current will become so limited that the potential in parts of the layer, during a period of alternating stress, may differ to such an extent from the earth potential that areas of the power transformer/reactor other than the solid insulation of the windings will be subjected to electric stress. By breaking the electric contact n amount of times, where n is an integral number and $n \geq 1$, in the second semiconducting layer between both ends of the cable and by earthing the second semiconducting layer at different phases in cross-connected manner at each said interruption, the current in the second semiconducting layer is eliminated

and the power losses are minimized.

All interruptions in the second, outer semiconducting layer of a high voltage cable will result in an increase of the electric field strength at the edge of the second semiconducting layer at the interruption. This increase of the electric field strength clearly increases the risk for electric breakdown. By arranging a means comprising a second insulation layer and a third semiconducting layer at each interruption in the second semiconducting layer, the risk for electric breakdown is minimized.

In extreme cases the windings may be subjected to such rapid transient overvoltage that parts of the outer semiconducting layer assume such a potential that areas of the power transformer other than the insulation of the cable are subjected to undesirable electric stress. In order to prevent such a situation from arising a number of non-linear elements, e.g. spark gaps, gas diodes, zener-diodes or varistors are connected between the layer and earth for each phase. By connecting a capacitor between the outer semiconducting layer and earth, undesirable electric stress may also be prevented from arising. A capacitor reduces the voltage stress even at 50Hz. This principle of earthing will be referred to below as "indirect earthing".

The indirectly earthed points are connected to earth either via the following;

- a non-linear element e.g. a spark gap or a gas diode,
- a non-linear element parallel to a capacitor,
- a capacitor

or a combination of all three alternatives.

The invention will now be described in more detail in the description hereinafter of the preferred embodiments of the invention with reference to the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 shows a cross-sectional view of a high voltage cable;

Figure 2A shows a partly sectional view of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field at the edges of the interruption; and

Figure 2B shows a perspective view of a part of the cable shown in Figure 2A;

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable on a

high voltage cable having a means to reduce the amplification of the electric field strength at the interruption;

Figure 4 shows a schematic principle of earthing a three phase power transformer according to the present invention;

Figure 5 is a diagram showing the potential of the second semiconducting layer in relation to the length of the cable;

Figure 6a and 6b, respectively, show different elements in order to achieve indirect earthing; and

Figure 7 shows a flow chart of the method of adapting a high voltage cable according to the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a cross-sectional view of a high voltage cable 10 traditionally used for the transmission of electric energy. The shown high voltage cable 10 may for example be a standard XLPE cable 145 kV but without a mantle and a screen. The cable 10 used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 97/45931. The high voltage cable 10 has an electric conductor which may include one or several strands 12 having a circular cross section of for example copper (Cu). These strands 12 are arranged centrally in the high voltage cable 10. Around the strands 12 there is arranged a first semiconducting layer 14. Around the first semiconducting layer 14 there is arranged a first insulating layer 16, of for example XLPE insulation. Around the first insulating layer 16 there is arranged a second semiconducting layer 18.

In fig. 1 showing the detail of the invention relating to the cable 10, the three layers 14, 16, 18 are arranged to adhere to each other even when the cable 10 is bent. The cable 10 shown is flexible, and this property is maintained during the entire life of the cable.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable includes an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and

an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer is made of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1} - 10^6 ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may be made of, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of $E < 500$ MPa, preferably < 200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Figure 2A shows a view, partially cross-sectional, of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field strength at the edges of the interruption. The section shown in 2A extends along the longitudinal axis of the high voltage cable. Figure 2B shows a perspective view of a part of the cable shown in Figure 2A. Like parts in Figures 2A and B have been designated

by the equivalent reference numbers. The strands 12 are only shown schematically in Figure 2A. As shown in Figures 2A and B the second semiconducting layer 18 has been removed in the shape of a ring around the periphery of the high voltage cable 10 so that a groove 20 is formed. In this way the first insulation layer 16 is exposed in the groove 20. By achieving this interruption in the electric contact located between two earthing points, in the second semiconducting layer 18, no current will flow and thus no loss of heat will occur due to induced voltage. However all interruptions in the second semiconducting layer 18 give rise to an amplification of the electric field strength at the sides of the interruption. As shown in Figure 2A, the electric field lines are illustrated (indicated by the reference number 22). At the edges of the groove 20 there is a concentration of field lines 22 which means that the electric field strength shows a sharp increase. This unfortunately results in an increased risk for electric discharge, the aim being to strive towards avoiding this occurrence.

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable of a high voltage cable having a mechanism to reduce the amplification of the electric field strength at the interruption. The high voltage cable 10 includes, in the same way as the high voltage cable according to Figure 1, the following: strands 12; a first semiconducting layer 14; a first insulating layer 16 and a second semiconducting layer 18. As shown in Figure 3 the second semiconducting layer 18 has been removed in the shape of a ring around the periphery so that a groove 20 is formed, exposing the first insulating layer 16. As shown in Figure 3 the groove 20 has downward sloping edges i.e. the groove 20 has a larger breadth at the upper edge of the second semiconducting layer 18 than that of the first insulating layer 16. The groove 20 may for example have straight edges even though downward sloping edges are advantageous. The distance between the edges of the second semiconducting layer 18 of the first insulating layer is indicated by b in Figure 3. The width b of the groove 20 is preferably 10 mm. Besides, the high voltage cable 10 includes a second insulating layer 24 which is applied among other things onto the groove 20 so that the groove 20 is filled in this way. The reason for having sloping edges at the groove 20 is in order to avoid obtaining a hollow space at the edges when the second insulating layer 24 is formed by filling among other things the groove 20 with a suitable insulating material, for example insulating "self amalgamating" EPR-tape such as the insulating tape IV-tape®, IA 2332 from ABB Kabeldon. The second insulating layer 24 covers even the sloping edges of the second semiconducting layer 18 and a part of the second semiconducting layer 18 to the side of the

sloping edges. Besides, the high voltage cable 10 has a third semiconducting layer 26, for example in the form of tape such as the semiconducting tape, HL-tape®, IA 2352 from ABB Kabeldon, which is applied over the second insulating layer 24 in such a way that the one end of the third semiconducting layer 26 covers one edge of the second insulating layer 24 and has electric contact to the second semiconducting layer 18. The other end of the third semiconducting layer 26 does not cover the other side of the second insulating layer 24 but stops at a distance c from the other edge of the second insulating layer 24. The second insulating layer 24 should at least be 1 mm thick at the edge where the third semiconducting layer 26 does not cover the second semiconducting layer 24. However, the third semiconducting layer 26 must be stretched at its other end over (overlapping) the second semiconducting layer 18 located under the second insulating layer 24. The distance between the edge of the third semiconducting layer 26 and the edge of the second semiconducting layer 18 in the longitudinal direction of the cable 10 is d as shown in Figure 3. The third semiconducting layer 26 should be at least 1 mm thick.

Figure 4 shows schematically the earthing principle for a three phase power transformer/reactor in accordance with the present invention. Windings are shown as drawn out cables in order to clarify the Figure. Besides, a possible core of the three phase power transformer has been omitted. Three phase power transformers comprise three windings 1, 2, 3 representing the different phases 1, 2, 3. Each winding 1, 2, 3 is constructed with the high voltage cable 10 shown in Figure 1. The cables for the different phases are designated as 10_1 , 10_2 , 10_3 . The second semiconducting layer of each high voltage cable $10_1, 10_2, 10_3$ is directly earthed at the points 32, 34 which are located at or in the vicinity of both ends of each winding 1, 2, 3. Generally, the second semiconducting layer 18 is directly earthed at n points of each winding 1, 2, 3, where n is an integral number and $n \geq 2$, and whereby two of said directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This direct earthing is performed by way of a galvanic connection to earth. Besides, the electric contact in the second semiconducting layer is interrupted two times $20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32}$ per winding 1, 2, 3. The electric contact in the second semiconducting layer 18 is generally interrupted $2(n-1)$ times per winding 1, 2, 3. Even if not shown in Figure 4 there may be found arranged at each such interruption 20 a mechanism 24, 26 having a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric field strength at said interruption 20. This mechanism 24, 26 is

shown in Figure 3. The second semiconducting layer 18 of the three phases 1, 2, 3 at each interruption 20_{11} , 20_{21} , 20_{31} , 20_{12} , 20_{22} , 20_{32} is earthed in a cross-connected manner. Besides, the second semiconducting layers 18 of the three phases 1, 2, 3 are indirectly earthed at two points 36, 38. Generally speaking, the number of indirectly earthed points may vary. As in the shown case the indirect earthing is performed by way of spark gaps 40. The indirect earthing may be performed in a number of different ways as for example in the aforementioned under the heading "Summary of the invention" and as shown in the Figures 6a, 6b. Cross-connected earthing 42, 44 is achieved through the second semiconducting layers 18 of the different phases 1, 2, 3 being connected at each said interruption 20_{11} , 20_{21} , 20_{31} , 20_{12} , 20_{22} , 20_{32} and being indirectly earthed via a spark gap 40. A more detailed description of cross-connected earthing will be discussed hereinafter.

The power transformer 30 in Figure 4 is provided with two interruptions 20_{11} , 20_{21} , 20_{31} , 20_{12} , 20_{22} , 20_{32} per phase 1, 2, 3 and thus three continuous sections 18_{11} , 18_{12} , 18_{13} ; 18_{21} , 18_{22} , 18_{23} ; 18_{31} , 18_{32} , 18_{33} of the second semiconducting layer 18 per phase 1, 2, 3. At the first interruption 20_{11} , the first section 18_{11} of the second semiconducting layer 18 of the first phase 1 is connected to the second section 18_{22} of the second phase 2. Besides, the first section 18_{11} of the first phase 1 is connected to the first section 18_{21} , 18_{31} of the remaining phases 2, 3 and connected to indirect earthing by way of a spark gap 40. The first section 18_{21} of the second phase 2 is connected to the second section 18_{32} of the third phase 3. Besides, the second section 18_{12} of the first phase 1 is connected to indirect earthing by means of the spark gap 40. Correspondingly, cross-connected earthing is applied to the second interruption 20_{12} and is not repeated herein. Another way of describing this cross-connected earthing is to follow the connections from a direct earthing point to the next earthing point. To start with the direct earthing point 32, is followed by the first section 18_{11} of the first phase 1, which section 18_{11} is connected to the second section 18_{22} of the second phase 2, which section 18_{22} is connected to the third section 18_{33} of the third phase 3, which is connected to direct earth via the point 34. Correspondingly, sections 18_{21} - 18_{32} - 18_{13} are connected between both of the direct earthing points 32, 34. Correspondingly, sections 18_{31} - 18_{12} - 18_{23} are connected between both of the direct earthing points 32, 34. However, a general description of cross-connected earthing in a power transformer/reactor will be described hereinafter where there are n number of direct earthing points per phase.

Generally speaking from the point of view of one case, the second semiconducting

layer 18 is directly earthed at n number of points of each winding 1, 2, 3 where n is an integral number and $n \geq 2$, and whereby two of said n directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This means that the electric contact is interrupted $20 \cdot 2(n-1)$ amount of times in the second semiconducting layer 18 between both ends, seeing that there are two interruptions 20 between each pair having directly earthed points. This means that there exists $3(n-1)$ sections of the second semiconducting layer 18 per phase 1, 2, 3, whereby one section begins at a directly earthed point or interruption 20 and ends at an interruption 20 or a directly earthed point.

At interruption 20 number q , where $1 \leq q \leq 2(n-1)$, of the different phases there is section r , where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer 18 of one phase which is connected to section $(r+1)$ of the second semiconducting layer 18 of the consecutive phase. Besides, section r of the first phase is connected to section r of the remaining phases. Section r of the last phase and section $(r+1)$ of the first phase are connected to the indirect earthing by means of a spark gap 40. The aforementioned does not apply to r evenly divisible by 3, except for the last section, i. e. $r=3(n-1)$ for a given n .

Figure 5 shows a diagram illustrating the potential of the second semiconducting layer 18 extending along the length of the cable. A power transformer having a Y connected winding is referred to in this case. This results then in that the voltage on the second semiconducting layer of the cable winding reduces linearly from the HV-connection to the neutral point under AC-voltage. Let the direct earthing points be designated A and D, and the two points for cross-connected earthing be designated B and C. Designate the distance between the direct earthing points A and D as L , the distance between A and B as I_1 , the distance between B and C as I_2 and the distance between C and D as I_3 . If the ratio between the distance I_1 , I_2 and I_3 is $I_1 < I_2 < I_3$, and the surface potentials of the second semiconducting layer at the points B and C have the same value, as indicated in Figure 5, the current will be 0 in the second semiconducting layer, which means that the power losses in the second semiconducting layer will be negligible. The distances I_1 , I_3 and L are dependent on the dimension of the winding cable in addition to the thickness and the resistivity of the second semiconducting layer.

Figures 6a and 6b respectively, illustrate different elements in order to achieve indirect earthing. In Figure 6a, indirect earthing takes place by means of a circuit 50 comprising one element 52 having a non-linear voltage-current characteristic which is

connected in parallel with a capacitor 54. In the shown case, the element 52 having a non-linear voltage-current characteristic is designed having one spark gap 52. The element 52 may also be designed having a gas-filled gas diode, a zener-diode or a varistor. In Figure 6b, indirect earthing takes place by means of a zener-diode 56.

Figure 7 shows a flow chart illustrating a method for adjusting a high voltage cable 10 (compare to Figure 1) comprising an electric conductor around which there is arranged a first semiconducting layer 14, around the first semiconducting layer 14 there is arranged a first insulating layer 16, and around the first insulating layer 16 there is arranged a second semiconducting layer 18. The method in accordance with the invention comprises a number of steps which will be described hereinafter. The flow chart starts at block 60. The next step, at block 62, is to indirectly earth 32, 34 the second semiconducting layer 18 at n points of each winding 1, 2, 3 where n is an integral number and $n \geq 2$, and whereby two of said n points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. Thereafter, at block 64, two interruptions 20 are achieved between each pair of directly earthed points in the electric contact in the second semiconducting layer 18. Thereafter, at block 66, a mechanism 24, 26 is applied at each interruption 20 in the second semiconducting layer 18, which mechanism comprises a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric field at interruption 20. Thereafter, at block 68, the second semiconducting layers of the different phases 1, 2, 3 are earthed in cross-connected manner at each said interruption 20. Thereafter, at block 70 at least one point 36, 38 of the second semiconducting layer 18 of each phase 1, 2, 3 is indirectly earthed between both ends. The method is concluded at block 72. Reference is made to Figures 2 - 6 regarding further details relating to the method.

It should be indicated that power transformers/reactors may be manufactured with a magnetizable core and also manufactured without a magnetizable core.

The invention is not limited to the embodiments described in the foregoing, several modifications are possible within the scope of the appended claims.

CLAIMS

1. A power transformer/reactor comprising at least one winding (1, 2, 3) characterized in that the winding/windings (1, 2, 3) are manufactured with a high voltage cable (10), comprising an electric conductor, around the conductor there being arranged a first semiconducting layer (14), around the first semiconducting layer (14) there being arranged a first insulating layer (16) and around the first insulating layer (16) there being arranged a second semiconducting layer (18), whereby the second semiconducting layer (18) is directly earthed (32, 34) at n points of each winding (1, 2, 3), where n is an integral number and $n \geq 2$, and whereby two (32, 34) of said n directly earthed points are arranged at or in the vicinity of both ends of each winding (1, 2, 3), whereby the electric contact is interrupted (20) $2(n-1)$ number of times between both ends in the second semiconducting layer (18), whereby the second semiconducting layers (18) of different phases (1, 2, 3) at each said interruption (20) is earthed in a cross-connected manner (42, 44).

2. A power transformer/reactor according to claim 1, characterized in that at least one point (36, 38) between both ends is indirectly earthed (40).

3. A power transformer/reactor according to claim 1, characterized in that at each said interruption (20) in the second semiconducting layer (18) there is arranged a third semiconducting layer (26) in order to reduce the amplification of the electric field strength at said interruption (20).

4. A power transformer/reactor according to any one of claims 1-3, characterized in that the electric contact in the second semiconducting layers (18) are interrupted in that the second semiconducting layer (18) being removed around the periphery of the high voltage cable (10) down to the first insulating layer (16) so that grooves (20) surrounded by the second semiconducting layer (18) are formed.

5. A power transformer/reactor according to claim 4, characterized in that the second insulating layer (24) is arranged onto each groove (20), besides which the layer (24) covers a part of the second semiconducting layer (18) on both sides of each groove (20), and that the third semiconducting layer (26) is arranged at the second insulating layer (24), whereby the

one end of the third semiconducting layer (26) covers the one edge of the second insulating layer (24) and has electric contact to the second semiconducting layer (18), and that the other end of the third semiconducting layer (26) does not cover the other edge of the second insulating layer (24) but extends along part of the second semiconducting layer (18) located under the second insulating layer (24).

6. A power transformer/reactor according to claim 5, characterized in that the edges of the second semiconducting layer (18) at said grooves (20) slope in such a way that the grooves (20) have the least width at the first insulating layer (16).

7. A power transformer/reactor according to claim 6, characterized in that the third semiconducting layer (26) at the end covering the edge of the second insulating layer (24) has mechanical contact with the second semiconducting layer (18), and that the other end of the third semiconducting layer (26) does not have mechanical or electric contact with the second semiconducting layer (18).

8. A power transformer/reactor according to any one of claims 1-7, characterized in that the high voltage cable (10) is manufactured having a conductor area which is between 80 and 3000 mm² and an outer cable diameter which is between 20 and 250 mm.

9. A power transformer/reactor according to any one of claims 1-8, characterized in that there are two interruptions (20) between two consecutive direct earthing points (32, 34).

10. A power transformer/reactor according to any one of claims 1-8, characterized in that each cross-connected earthing is formed by the second semiconducting layers (18) of the different phases (1, 2, 3) at each said interruption (20) being connected and indirectly earthed (40).

11. A power transformer/reactor according to claim 10, characterized in that there are 2(n-1) number of interruptions (20₁₁, 20₁₂, 20₂₁, 20₂₂; 20₃₁, 20₃₂) per phase and thus 3(n-1) connected sections of the second semiconducting layer (18₁₁, 18₁₂, 18₁₃; 18₂₁, 18₂₂, 18₂₃; 18₃₁, 18₃₂, 18₃₃) per phase, and that also at interruption (20) number q, where 1 ≤ q ≤ 2(n-1), of the

different phases (1, 2, 3) section r , where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer (18) of one phase (1; 2; 3) is connected to section $(r+1)$ of the second semiconducting layer (18) of the consecutive phase, and that section r of the second semiconducting layer (18) of the first phase (1) is connected to section r of the second semiconducting layer (18) of the remaining phases (2, 3), and that section r of the second semiconducting layer (18) of the last phase (3) and section $(r+1)$ of the second semiconducting layer (18) of the first phase (1) are connected to the indirect earthing (40), whereby the aforementioned does not apply to r evenly divisible by 3, except for the last section, i.e. $r=3(n-1)$.

12. A power transformer/reactor according to any one of claims 1-11, characterized in that the direct earthing (32, 34) is performed by means of galvanic connection to earth.

13. A power transformer/reactor according to any one of claims 1-12, characterized in that the indirect earthing is performed by means of a capacitor which is connected between the second semiconducting layer (18) and earth.

14. A power transformer/reactor according to any one of claims 1-12, characterized in that the indirect earthing is performed by means of an element, connected between the second semiconducting layer (18) and earth, having a non-linear voltage-current characteristic.

15. A power transformer/reactor according to any one of claims 1-12, characterized in that the indirect earthing is performed by means a circuit (50) comprising an element, connected between the second semiconducting layer (18) and earth, having a non-linear voltage-current characteristic (52) connected in parallel with a capacitor (54).

16. A power transformer/reactor according to claim 15, characterized in that the indirect earthings are performed by means of a combination of alternatives according to claims 13-15.

17. A power transformer/reactor according to any one of claims 14-16, characterized in that the element (52) having a non-linear voltage-current characteristic may be designed

with a spark gap (52), a gas-filled gas diode, a zener-diode (56) or varistor.

18. A power transformer/reactor according to any one of claims 1-17, characterized in that the power transformer/reactor comprises a magnetizable core.

19. A power transformer/reactor according to any one of claims 1-17, characterized in that the power transformer/reactor is manufactured without a magnetizable core.

20. A power transformer/reactor according to any one of claims 1-19, characterized in that said layers (14, 16, 18) are arranged to adhere to one another even when the cable is bent.

21. A method for adjusting a high voltage cable (10) for windings in a power transformer/reactor which high voltage cable (10) comprises an electric conductor, around which there is arranged a first semiconducting layer (14), around the first semiconducting layer (14) there is arranged a first insulating layer (16), and around the first insulating layer (16) there is arranged a second semiconducting layer (18), which method comprises the following steps:

- to directly earth (32, 34) the second semiconducting layer (18) at n points of each winding (1, 2, 3), where n is an integral number and $n \geq 2$, and whereby two (32, 34) of said n points are arranged at or in the vicinity of both ends of each winding (1, 2, 3);
- to achieve two interruptions (20) between each pair of directly earthed points in the electric contact in the second semiconducting layer (18); and
- to earth in cross-connected manner the second semiconducting layer (18) of the different phases (1, 2, 3) at each said interruption (20);

22. A method according to claim 21, characterized in that said method comprises furthermore the step:

- to indirectly earth at least one point (36, 38) in each phase between both ends of the second semiconducting layer (18).

23. A method according to any one of claims 21-22, characterized in that said method comprises furthermore the step:

- to apply a third semiconducting layer (26) at each said interruption (20) in the second semiconducting layer (18) in order to reduce the amplification of the electric field strength at said interruption (20).

24. A method according to any one of claims 21-23, characterized in that each said interruption (20) is achieved by removing the second semiconducting layer (18) around the periphery of the high voltage cable (10) down to the first insulating layer (16) so that grooves (20) surrounded by the second semiconducting layer (18) are formed.

25. A method according to claim 24, characterized in that the step of applying said means (24, 26) comprises the following steps:

- to apply a second insulating layer (24) over each groove (20) in such a way that part of the second semiconducting layer is (18) on both sides of each groove (20) is additionally covered; and
- to apply a third semiconducting layer (26) on the second insulating layer (24) in such a way that the one end of the third semiconducting layer (26) covers the one edge of the second insulating layer (24) and has electric contact to the second semiconducting layer (18), and the other end of the third semiconducting layer (18) does not cover the other edge of the second insulating layer (24) but extends along a part of the second semiconducting layer (18) located under the second insulating layer (24).

26. A method according to any one of claims 21-25, characterized in that the step to earth in cross-connected manner comprises the following step:

- to connect the second semiconducting layer of the different phases (1, 2, 3) at each said interruption (20), and indirectly earthing the aforementioned.

27. A method according to claim 26, characterized in that the step to earth in cross-connected manner comprises furthermore the following steps; whereby the number of interruptions (20_{11} , 20_{12} ; 20_{21} , 20_{22} ; 20_{31} , 20_{32}) per phase are $2(n-1)$ and the number of

connected sections of the second semiconducting layer ($18_{11}, 18_{12}, 18_{13}; 18_{21}, 18_{22}, 18_{23}; 18_{31}, 18_{32}, 18_{33}$) per phase are $3(n-1)$:

- to connect at interruption (20) number q , where $1 \leq q \leq 2(n-1)$, of the different phases (1, 2, 3), section r , where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer (18) of one phase (1, 2, 3) to section $(r+1)$ of the second semiconducting layer of the consecutive phase;
- to connect section r of the second semiconducting layer (18) of the first phase (1) to section r of the second semiconducting layer (18) of the remaining phases (2, 3); and
- to connect section r of the second semiconducting layer (18) of the last phase (3) and section $(r+1)$ of the second semiconducting layer (18) of the first phase (1) to the indirect earthing (40), whereby the aforementioned does not apply to section r , where r is evenly divisible by 3, except for the last section, i. e. $r=3(n-1)$.

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POWER TRANSFORMER/REACTOR AND A METHOD OF ADAPTING A HIGH VOLTAGE CABLE

Technical field

5 The present invention relates in a first aspect to a power transformer/reactor. A second aspect of the present invention relates to a method of adapting a high voltage cable for windings of a power transformer/reactor.

10 For all transmission and distribution of electric energy, transformers are used and their task is to allow exchange of electric energy between two or more electric systems having generally different voltage levels. Transformers are available in all power ranges from the VA up to the 1000 MVA range. With respect to the voltage range, there is a spectrum up to the highest transmission voltages which are being used today. Electromagnetic induction is used for the transmission of energy between electric systems.

15 For the transmission of electric energy, reactors are also included as an essential component, for example for phase compensation and filtering.

20 The transformer/reactor relating to the present invention belongs to the so-called power transformers/reactors with a rated output ranging from a few hundred kVA up to more than 1000 MVA with a rated voltage ranging from 3-4 kV and up to very high transmission voltages.

Background of the invention

25 From a purely general point of view, the primary task of a power transformer is to allow exchange of electric energy between two or more electrical systems usually having different voltages with the same frequency.

30 A conventional power transformer/reactor comprises a transformer core referred to below as core, made of laminated preferably oriented sheets, usually of silicon steel. The core consists of a number of core legs connected by yokes. Around the core legs there are a number of windings which are normally referred to as primary, secondary and regulation winding. As far as power transformers are concerned these windings are practically always concentrically arranged and distributed along the length of the core legs.

Other types of core constructions occasionally occur such as those of the so-called shell-type transformer or the toroidal-type transformer. Examples relating to core constructions are described in for example DE 40414. The core may consist of conventional magnetizable material such as said oriented steel sheet, and of
5 other magnetizable material such as ferrites, amorphous material, wire strands or metal tape. With respect to reactors, the magnetizable core is as known not necessary.

The above-mentioned windings constitute one or several coils connected in series, which coils are constructed of a number of turns connected in series. The
10 turns of a single coil normally make up a geometrically continuous unit which is physically separated from the remaining coils.

The insulation system, partly on the inside of a coil/winding and partly between coils/windings and other metal parts is normally in the form of a solid cellulose or varnish based insulation closest to the separate conducting element and the
15 insulation on the outside is in the form of a solid cellulose insulation, a fluid insulation and possibly an insulation in the form of a gas. Windings having insulation and possible bulky parts represent in this way large volumes that will be subjected to high electric field strengths occurring in and around the active electro-magnetic parts belonging to transformers. A detailed knowledge of the properties of insulation
20 material is required in order to predetermine the dielectric field strengths which arise and in order to attain a dimensioning such that there is a minimal risk of electric breakdown. Furthermore it is essential to achieve a surrounding environment which does not change or lead to the deterioration of the insulation properties.

Today's predominant outer insulation system for conventional high voltage
25 power transformers/reactors consists of cellulose material for the solid insulation and transformer oil for the fluid insulation. Transformer oil is based on so-called mineral oil.

Additionally, a conventional insulation is relatively complicated to construct and special measures need to be taken during manufacture in order to utilize the
30 good insulation properties of the insulation system. The system should have a low moisture content, the solid phase in the insulation system needs to be well impregnated with the surrounding liquid, the risk for remaining gas pockets in the solid phase must be minimal. During manufacture a special drying process is carried out

on the complete core with windings before it is lowered into the tank. After lowering the core and sealing the tank, the latter is emptied of all air by means of a special vacuum treatment before being filled with oil. This process is relatively time consuming seen from the entire manufacturing process in addition to requiring the extensive utilization of resources in the workshop.

The tank surrounding the transformer must be constructed in such a way that is able to withstand full vacuum since the process requires that all the gas be pumped out to almost absolute vacuum which involves extra material consumption and manufacturing time.

Furthermore, the installation on site requires renewed vacuum treatment, a process to be repeated each time the transformer is opened for attention or for inspection.

Summary of the invention

The power transformer/reactor, according to the present invention, comprises at least one winding arranged in most cases around a magnetizable core which is of varying geometry. The term "windings" will preferably be referred to below in order to simplify the following specification. The windings are formed of a high voltage cable having solid insulation. The cables consist of at least one centrally located electric conductor around which there is arranged a first semiconducting layer, around the first semiconducting layer there is arranged a solid first insulating layer and around the insulating layer there is arranged a second outer semiconducting layer.

An additional advantage is that said layers are arranged to adhere to one another even when the cable is bent. Hereby, good contact is achieved between the layers during the cable's entire life.

The second semiconducting layer is directly earthed at n points of each winding, where n is an integral number and $n \geq 2$, and whereby two of said directly earthed points are arranged at or in the vicinity of both ends of each winding. The electric contact is interrupted $2(n-1)$ times in the second semiconducting layer. The second semiconducting layer of different phases at each said interruption is earthed in a cross-connected manner.

A method for adapting a high voltage cable for windings of a power transformer/reactor, according to the present invention, comprises the following steps:

- directly earthing the second semiconducting layer at n points of each winding where n is an integral number and $n \geq 2$, and whereby two of said points are arranged at or in the vicinity of both ends of each winding;
- achieving two interruptions in the electric contact in the second semiconducting layer between each pair of directly earthed points; and
- earthing in a cross-connected manner the second semiconducting layer at different phases of each said interruption.

The use of such a cable implies that those areas of the transformer/reactor which are subjected to high electric field stress are limited to the solid insulation of the cable. Remaining parts of the transformer/reactor, with respect to high voltage application, are only subjected to very moderate electric field strengths. Furthermore, the use of such a cable eliminates several problematic areas described in the background of the invention. Consequently a tank is not needed for the insulating and cooling medium. Besides, the insulation also becomes substantially simple. Construction time is considerably shorter compared to that of a conventional power transformer/reactor. The windings may be manufactured separately and the power transformer/reactor may be assembled on site.

However, the use of such a cable presents new problems which must be solved. The outer semiconducting layer must be directly earthed at or in the vicinity of both ends of the cable so that the electric stress, which arises both at normal operating voltage and during transience, will primarily only load the solid insulation of the cable. The semiconducting layer in addition to these direct earthings form a closed circuit in which a current is induced during operation. The resistivity of the layer must be great enough so that the resistive losses arising in the layer are negligible.

Besides this magnetically induced current, a capacitive current will flow into the layer through the direct earthing in both ends of the cable. If the resistivity of the layer is too great, the capacitive current will become so limited that the potential in parts of the layer, during a period of alternating stress, may differ to such an extent from the earth potential that areas of the power transformer/reactor other than the

solid insulation of the windings will be subjected to electric stress. By breaking the electric contact n amount of times, where n is an integral number and $n \geq 1$, in the second semiconducting layer between both ends of the cable and by earthing the second semiconducting layer at different phases in cross-connected manner at
5 each said interruption, the current in the second semiconducting layer is eliminated and the power losses are minimized.

All interruptions in the second, outer semiconducting layer of a high voltage cable will result in an increase of the electric field strength at the edge of the second semiconducting layer at the interruption. This increase of the electric field strength
10 clearly increases the risk for electric breakdown. By arranging a means comprising a second insulation layer and a third semiconducting layer at each interruption in the second semiconducting layer, the risk for electric breakdown is minimized.

In extreme cases the windings may be subjected to such rapid transient overvoltage that parts of the outer semiconducting layer assume such a potential
15 that areas of the power transformer other than the insulation of the cable are subjected to undesirable electric stress. In order to prevent such a situation from arising a number of non-linear elements, e.g. spark gaps, gas diodes, zener-diodes or varistors are connected between the layer and earth for each phase. By connecting a capacitor between the outer semiconducting layer and earth, undesirable electric
20 stress may also be prevented from arising. A capacitor reduces the voltage stress even at 50Hz. This principle of earthing will be referred to below as "indirect earthing".

The indirectly earthed points are connected to earth either via the following;

- a non-linear element e.g. a spark gap or a gas diode,
 - 25 • a non-linear element parallel to a capacitor,
 - a capacitor
- or a combination of all three alternatives.

The invention will now be described in more detail in the description here-
30 inafter of the preferred embodiments of the invention with reference to the accompanying drawings.

Brief description of the drawings

Figure 1 shows a cross-sectional view of a high voltage cable;

Figure 2A shows a partly sectional view of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field at the edges of the interruption; and

5 Figure 2B shows a perspective view of a part of the cable shown in Figure 2A;

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable on a high voltage cable having a means to reduce the amplification of the electric field strength at the interruption;

Figure 4 shows a schematic principle of earthing a three phase power transformer according to the present invention;

Figure 5 is a diagram showing the potential of the second semiconducting layer in relation to the length of the cable;

Figure 6a and 6b, respectively, show different elements in order to achieve indirect earthing ; and

15 Figure 7 shows a flow chart of the method of adapting a high voltage cable according to the present invention.

Detailed description of the embodiments of the present invention

Figure 1 shows a cross-sectional view of a high voltage cable 10 traditionally used for the transmission of electric energy. The shown high voltage cable 10 may for example be a standard XLPE cable 145 kV but without a mantle and a screen. The cable 10 used in the present invention is flexible and of a kind which is described in more detail in WO 97/45919 and WO 97/45847. Additional descriptions of the cable concerned can be found in WO 97/45918, WO 97/45930 and WO 25 97/45931. The high voltage cable 10 comprises an electric conductor which may comprise one or several strands 12 having a circular cross section of for example copper (Cu). These strands 12 are arranged centrally in the high voltage cable 10. Around the strands 12 there is arranged a first semiconducting layer 14. Around the first semiconducting layer 14 there is arranged a first insulating layer 16, of for example XLPE insulation. Around the first insulating layer 16 there is arranged a 30 second semiconducting layer 18.

In fig. 1 showing the detail of the invention relating to the cable 10, the three layers 14, 16, 18 are arranged to adhere to each other even when the cable 10 is

bent. The cable 10 shown is flexible, and this property is maintained during the entire life of the cable.

Accordingly, the windings, in the arrangement according to the invention, are preferably of a type corresponding to cables having solid, extruded insulation, of a type now used for power distribution, such as XLPE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strand parts, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the arrangement according to the invention is based primarily on winding systems in which the winding is formed from cable which is bent during assembly. The flexibility of an XLPE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable with a diameter of 30 mm, and a radius of curvature of approximately 65 cm for a cable with a diameter of 80 mm. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative coefficients of thermal expansion. In an XLPE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius in the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1} - 10^6

ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentene ("TPX"), cross-linked materials such as cross-linked polyethylene (XLPE), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymers/nitrile rubber (EVA/NBR), butyl graft polyethylene, ethylene-butyl-acrylate copolymers (EBA) and ethylene-ethyl-acrylate copolymers (EEA) may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be substantially the same. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of $E < 500$ MPa, preferably < 200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks appear, or any other damage, and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently high to enclose the electrical field within the cable, but sufficiently low not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and these layers will substantially enclose the electrical field between them.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

Figure 2A shows a view, partially cross-sectional, of a high voltage cable having interruptions in the second semiconducting layer in order to illustrate the amplification of the electric field strength at the edges of the interruption. The section shown in 2A extends along the longitudinal axis of the high voltage cable. Figure 2B shows a perspective view of a part of the cable shown in Figure 2A. Like parts in Figures 2A and B have been designated by the equivalent reference numbers. The strands 12 are only shown schematically in Figure 2A. As shown in Figures 2A and B the second semiconducting layer 18 has been removed in the shape of a ring around the periphery of the high voltage cable 10 so that a groove 20 is formed. In this way the first insulation layer 16 is exposed in the groove 20. By achieving this interruption in the electric contact located between two earthing points, in the second semiconducting layer 18, no current will flow and thus no loss of heat will occur due to induced voltage. However all interruptions in the second semiconducting layer 18 give rise to an amplification of the electric field strength at the sides of the interruption. As shown in Figure 2A, the electric field lines are illustrated (indicated by the reference number 22). At the edges of the groove 20 there is a concentration of field lines 22 which means that the electric field strength shows a sharp increase. This unfortunately results in an increased risk for electric discharge, the aim being to strive towards avoiding this occurrence.

Figure 3 shows a cross-sectional view along the longitudinal axis of the cable of a high voltage cable having a means to reduce the amplification of the electric field strength at the interruption. The high voltage cable 10 comprises, in the same way as the high voltage cable according to Figure 1, the following: strands 12; a first semiconducting layer 14; a first insulating layer 16 and a second semiconducting layer 18. As shown in Figure 3 the second semiconducting layer 18 has been removed in the shape of a ring around the periphery so that a groove 20 is formed, exposing the first insulating layer 16. As shown in Figure 3 the groove 20 has downward sloping edges i.e. the groove 20 has a larger breadth at the upper edge of the

second semiconducting layer 18 than that of the first insulating layer 16. The groove 20 may for example have straight edges even though downward sloping edges are advantageous. The distance between the edges of the second semiconducting layer 18 of the first insulating layer is indicated by b in Figure 3. The width b of the groove 20 is preferably 10 mm. Besides, the high voltage cable 10 comprises a second insulating layer 24 which is applied among other things onto the groove 20 so that the groove 20 is filled in this way. The reason for having sloping edges at the groove 20 is in order to avoid obtaining a hollow space at the edges when the second insulating layer 24 is formed by filling among other things the groove 20 with a suitable insulating material, for example insulating "self amalgamating" EPR-tape such as the insulating tape IV-tape®, IA 2332 from ABB Kabeldon. The second insulating layer 24 covers even the sloping edges of the second semiconducting layer 18 and a part of the second semiconducting layer 18 to the side of the sloping edges. Besides, the high voltage cable 10 comprises a third semiconducting layer 26, for example in the form of tape such as the semiconducting tape, HL-tape®, IA 2352 from ABB Kabeldon, which is applied over the second insulating layer 24 in such a way that the one end of the third semiconducting layer 26 covers one edge of the second insulating layer 24 and has electric contact to the second semiconducting layer 18. The other end of the third semiconducting layer 26 does not cover the other side of the second insulating layer 24 but stops at a distance c from the other edge of the second insulating layer 24. The second insulating layer 24 should at least be 1 mm thick at the edge where the third semiconducting layer 26 does not cover the second semiconducting layer 24. However, the third semiconducting layer 26 must be stretched at its other end over (overlapping) the second semiconducting layer 18 located under the second insulating layer 24. The distance between the edge of the third semiconducting layer 26 and the edge of the second semiconducting layer 18 in the longitudinal direction of the cable 10 is d as shown in Figure 3. The third semiconducting layer 26 should be at least 1 mm thick.

Figure 4 shows schematically the earthing principle for a three phase power transformer/reactor in accordance with the present invention. Windings are shown as drawn out cables in order to clarify the Figure. Besides, a possible core of the three phase power transformer has been omitted. Three phase power transformers comprise three windings 1, 2, 3 representing the different phases 1, 2, 3. Each

winding 1, 2, 3 is constructed with the high voltage cable 10 shown in Figure 1. The cables for the different phases are designated as $10_1, 10_2, 10_3$. The second semiconducting layer of each high voltage cable $10_1, 10_2, 10_3$ is directly earthed at the points 32, 34 which are located at or in the vicinity of both ends of each winding 1, 2, 3. Generally, the second semiconducting layer 18 is directly earthed at n points of each winding 1, 2, 3, where n is an integral number and $n \geq 2$, and whereby two of said directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This direct earthing is performed by means of a galvanic connection to earth. Besides, the electric contact in the second semiconducting layer is interrupted two times $20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32}$ per winding 1, 2, 3. The electric contact in the second semiconducting layer 18 is generally interrupted $2(n-1)$ times per winding 1, 2, 3. Even if not shown in Figure 4 there may be found arranged at each such interruption 20 a means 24, 26 comprising a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric field strength at said interruption 20. This means 24, 26 is shown in Figure 3. The second semiconducting layer 18 of the three phases 1, 2, 3 at each said interruption $20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32}$ is earthed in a cross-connected manner. Besides, the second semiconducting layers 18 of the three phases 1, 2, 3 are indirectly earthed at two points 36, 38. Generally speaking, the number of indirectly earthed points may vary. As in the shown case the indirect earthing is performed by means of spark gaps 40. The indirect earthing may be performed in a number of different ways as for example in the aforementioned under the heading "Summary of the invention" and as shown in the Figures 6a, 6b. Cross-connected earthing 42, 44 is achieved through the second semiconducting layers 18 of the different phases 1, 2, 3 being connected at each said interruption $20_{11}, 20_{21}, 20_{31}, 20_{12}, 20_{22}, 20_{32}$ and being indirectly earthed via a spark gap 40. A more detailed description of cross-connected earthing will be discussed hereinafter.

The power transformer 30 in Figure 4 is provided with two interruptions $20_{11}, 20_{12}; 20_{21}, 20_{22}; 20_{31}, 20_{32}$ per phase 1, 2, 3 and thus three continuous sections $18_{11}, 18_{12}, 18_{13}; 18_{21}, 18_{22}, 18_{23}; 18_{31}, 18_{32}, 18_{33}$ of the second semiconducting layer 18 per phase 1, 2, 3. At the first interruption 20_{11} , the first section 18_{11} of the second semiconducting layer 18 of the first phase 1 is connected to the second section 18_{22} of the second phase 2. Besides, the first section 18_{11} of the first phase

1 is connected to the first section 18_{21} , 18_{31} of the remaining phases 2, 3 and connected to indirect earthing by means of a spark gap 40. The first section 18_{21} of the second phase 2 is connected to the second section 18_{32} of the third phase 3. Besides, the second section 18_{12} of the first phase 1 is connected to indirect earthing by means of the spark gap 40. Correspondingly, cross-connected earthing is applied to the second interruption 20_{12} and is not repeated herein. Another way of describing this cross-connected earthing is to follow the connections from a direct earthing point to the next earthing point. To start with the direct earthing point 32, is followed by the first section 18_{11} of the first phase 1, which section 18_{11} is connected to the second section 18_{22} of the second phase 2, which section 18_{22} is connected to the third section 18_{33} of the third phase 3, which is connected to direct earth via the point 34. Correspondingly, sections 18_{21} - 18_{32} - 18_{13} are connected between both of the direct earthing points 32, 34. Correspondingly, sections 18_{31} - 18_{12} - 18_{23} are connected between both of the direct earthing points 32, 34. However, a general description of cross-connected earthing in a power transformer/reactor will be described hereinafter where there are n number of direct earthing points per phase.

Generally speaking from the point of view of one case, the second semiconducting layer 18 is directly earthed at n number of points of each winding 1, 2, 3 where n is an integral number and $n \geq 2$, and whereby two of said n directly earthed points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. This means that the electric contact is interrupted $2(n-1)$ amount of times in the second semiconducting layer 18 between both ends, seeing that there are two interruptions between each pair having directly earthed points. This means that there exists $3(n-1)$ sections of the second semiconducting layer 18 per phase 1, 2, 3, whereby one section begins at a directly earthed point or interruption 20 and ends at an interruption 20 or a directly earthed point.

At interruption 20 number q, where $1 \leq q \leq 2(n-1)$, of the different phases there is section r, where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer 18 of one phase which is connected to section (r+1) of the second semiconducting layer 18 of the consecutive phase. Besides, section r of the first phase is connected to section r of the remaining phases. Section r of the last phase and section (r+1) of the first phase are connected to the indirect earthing by means of a spark gap 40. The

aforementioned does not apply to r evenly divisible by 3, except for the last section, i. e. $r=3(n-1)$ for a given n .

Figure 5 shows a diagram illustrating the potential of the second semiconducting layer 18 extending along the length of the cable. A power transformer having a Y connected winding is referred to in this case. This results then in that the voltage on the second semiconducting layer of the cable winding reduces linearly from the HV-connection to the neutral point under AC-voltage. Let the direct earthing points be designated A and D, and the two points for cross-connected earthing be designated B and C. Designate the distance between the direct earthing points A and D as L , the distance between A and B as l_1 , the distance between B and C as l_2 and the distance between C and D as l_3 . If the ratio between the distance l_1 , l_2 and l_3 is $l_1 < l_2 < l_3$ and the surface potentials of the second semiconducting layer at the points B and C have the same value, as indicated in Figure 5, the current will be 0 in the second semiconducting layer, which means that the power losses in the second semiconducting layer will be negligible. The distances l_1 – l_3 and L are dependent on the dimension of the winding cable in addition to the thickness and the resistivity of the second semiconducting layer.

Figures 6a and 6b respectively, illustrate different elements in order to achieve indirect earthing. In Figure 6a, indirect earthing takes place by means of a circuit 50 comprising one element 52 having a non-linear voltage-current characteristic which is connected in parallel with a capacitor 54. In the shown case, the element 52 having a non-linear voltage-current characteristic is designed having one spark gap 52. The element 52 may also be designed having a gas-filled gas diode, a zener-diode or a varistor. In Figure 6b, indirect earthing takes place by means of a zener-diode 56.

Figure 7 shows a flow chart illustrating a method for adjusting a high voltage cable 10 (compare to Figure 1) comprising an electric conductor around which there is arranged a first semiconducting layer 14, around the first semiconducting layer 14 there is arranged a first insulating layer 16, and around the first insulating layer 16 there is arranged a second semiconducting layer 18. The method in accordance with the invention comprises a number of steps which will be described hereinafter. The flow chart starts at block 60. The next step, at block 62, is to indirectly earth the second semiconducting layer 18 at n points of each winding 1, 2, 3

where n is an integral number and $n \geq 2$, and whereby two of said n points are arranged at or in the vicinity of both ends of each winding 1, 2, 3. Thereafter, at block 64, two interruptions 20 are achieved between each pair of directly earthed points in the electric contact in the second semiconducting layer 18. Thereafter, at block 66, a means 24, 26 is applied at each said interruption 20 in the second semiconducting layer 18, which means comprises a second insulating layer 24 and a third semiconducting layer 26 in order to reduce the amplification of the electric field at said interruption 20. Thereafter, at block 68, the second semiconducting layers of the different phases 1, 2, 3 are earthed in cross-connected manner at each said interruption 20. Thereafter, at block 70 at least one point 36, 38 of the second semiconducting layer 18 of each phase 1, 2, 3 is indirectly earthed between both ends. The method is concluded at block 72. Reference is made to Figures 2 - 6 regarding further details relating to the method.

It should be indicated that power transformers/reactors may be manufactured with a magnetizable core and also manufactured without a magnetizable core.

The invention is not limited to the embodiments described in the foregoing, several modifications are possible within the scope of the appended claims.

CLAIMS

1. A power transformer/reactor comprising at least one winding (1, 2, 3) **characterized** in that the winding/windings (1, 2, 3) are manufactured with a high voltage cable (10), comprising an electric conductor, around the conductor there being arranged a first semiconducting layer (14), around the first semiconducting layer (14) there being arranged a first insulating layer (16) and around the first insulating layer (16) there being arranged a second semiconducting layer (18), whereby the second semiconducting layer (18) is directly earthed (32, 34) at n points of each winding (1, 2, 3), where n is an integral number and $n \geq 2$, and whereby two (32, 34) of said n directly earthed points are arranged at or in the vicinity of both ends of each winding (1, 2, 3), whereby the electric contact is interrupted (20) $2(n-1)$ number of times between both ends in the second semiconducting layer (18), whereby the second semiconducting layers (18) of different phases (1, 2, 3) at each said interruption (20) is earthed in a cross-connected manner (42, 44).
2. A power transformer/reactor according to claim 1, **characterized** in that at least one point (36, 38) between both ends is indirectly earthed (40).
3. A power transformer/reactor according to claim 1, **characterized** in that at each said interruption (20) in the second semiconducting layer (18) there is arranged a third semiconducting layer (26) in order to reduce the amplification of the electric field strength at said interruption (20),
4. A power transformer/reactor according to any one of claims 1-3, **characterized** in that the electric contact in the second semiconducting layers (18) are interrupted in that the second semiconducting layer (18) being removed around the periphery of the high voltage cable (10) down to the first insulating layer (16) so that grooves (20) surrounded by the second semiconducting layer (18) are formed.
5. A power transformer/reactor according to claim 4, **characterized** in that the second insulating layer (24) is arranged onto each groove (20), besides which the layer (24) covers a part of the second semiconducting layer (18) on both sides of

each groove (20), and that the third semiconducting layer (26) is arranged at the second insulating layer (24), whereby the one end of the third semiconducting layer (26) covers the one edge of the second insulating layer (24) and has electric contact to the second semiconducting layer (18), and that the other end of the third semiconducting layer (26) does not cover the other edge of the second insulating layer (24) but extends along part of the second semiconducting layer (18) located under the second insulating layer (24).

6. A power transformer/reactor according to claim 5, **characterized** in that the edges of the second semiconducting layer (18) at said grooves (20) slope in such a way that the grooves (20) have the least width at the first insulating layer (16).

7. A power transformer/reactor according to claim 6, **characterized** in that the third semiconducting layer (26) at the end covering the edge of the second insulating layer (24) has mechanical contact with the second semiconducting layer (18), and that the other end of the third semiconducting layer (26) does not have mechanical or electric contact with the second semiconducting layer (18).

8. A power transformer/reactor according to any one of claims 1 - 7, **characterized** in that the high voltage cable (10) is manufactured having a conductor area which is between 80 and 3000 mm² and an outer cable diameter which is between 20 and 250 mm.

9. A power transformer/reactor according to any one of claims 1 - 8, **characterized** in that there are two interruptions (20) between two consecutive direct earthing points (32, 34)

10. A power transformer/reactor according to any one of claims 1 - 8, **characterized** in that each cross-connected earthing is formed by the second semiconducting layers (18) of the different phases (1, 2, 3) at each said interruption (20) being connected and indirectly earthed (40).

11. A power transformer/reactor according to claim 10, **characterized** in that there are $2(n-1)$ number of interruptions (20_{11} , 20_{12} ; 20_{21} , 20_{22} ; 20_{31} , 20_{32}) per phase and thus $3(n-1)$ connected sections of the second semiconducting layer (18_{11} , 18_{12} , 18_{13} ; 18_{21} , 18_{22} , 18_{23} ; 18_{31} , 18_{32} , 18_{33}) per phase, and that also at interruption (20) number q, where $1 \leq q \leq 2(n-1)$, of the different phases (1, 2, 3) section r, where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer (18) of one phase (1; 2; 3) is connected to section (r+1) of the second semiconducting layer (18) of the consecutive phase, and that section r of the second semiconducting layer (18) of the first phase (1) is connected to section r of the second semiconducting layer (18) of the remaining phases (2, 3), and that section r of the second semiconducting layer (18) of the last phase (3) and section (r+1) of the second semiconducting layer (18) of the first phase (1) are connected to the indirect earthing (40), whereby the aforementioned does not apply to r evenly divisible by 3, except for the last section, i. e. $r=3(n-1)$.

12. A power transformer/reactor according to any one of claims 1 - 11, **characterized** in that the direct earthing (32, 34) is performed by means of galvanic connection to earth.

13. A power transformer/reactor according to any one of claims 1 - 12, **characterized** in that the indirect earthing is performed by means of a capacitor which is connected between the second semiconducting layer (18) and earth.

14. A power transformer/reactor according to any one of claims 1 - 12, **characterized** in that the indirect earthing is performed by means of an element, connected between the second semiconducting layer (18) and earth, having a non-linear voltage-current characteristic.

15. A power transformer/reactor according to any one of claims 1 - 12, **characterized** in that the indirect earthing is performed by means a circuit (50) comprising an element, connected between the second semiconducting layer (18) and earth, having a non-linear voltage-current characteristic (52) connected in parallel with a capacitor (54).

16. A power transformer/reactor according to claim 15, **characterized** in that the indirect earthings are performed by means of a combination of alternatives according to claims 13 - 15.

17. A power transformer/reactor according to any one of claims 14 - 16, **characterized** in that the element (52) having a non-linear voltage-current characteristic may be designed with a spark gap (52), a gas-filled gas diode, a zener-diode (56) or a varistor.

18. A power transformer/reactor according to any one of claims 1 - 17, **characterized** in that the power transformer/reactor comprises a magnetizable core.

19. A power transformer/reactor according to any one of claims 1 - 17, **characterized** in that the power transformer/reactor is manufactured without a magnetizable core.

20. A power transformer/reactor according to any one of claims 1 - 19, **characterized** in that said layers (14, 16, 18) are arranged to adhere to one another even when the cable is bent.

21. A method for adjusting a high voltage cable (10) for windings in a power transformer/reactor which high voltage cable (10) comprises an electric conductor, around which there is arranged a first semiconducting layer (14), around the first semiconducting layer (14) there is arranged a first insulating layer (16), and around the first insulating layer (16) there is arranged a second semiconducting layer (18), which method comprises the following steps:

- to directly earth (32, 34) the second semiconducting layer (18) at n points of each winding (1, 2, 3), where n is an integral number and $n \geq 2$, and whereby two (32, 34) of said n points are arranged at or in the vicinity of both ends of each winding (1, 2, 3);
- to achieve two interruptions (20) between each pair of directly earthed points in the electric contact in the second semiconducting layer (18); and

- to earth in cross-connected manner the second semiconducting layer (18) of the different phases (1, 2, 3) at each said interruption (20);

22. A method according to claim 21, **characterized** in that said method comprises furthermore the step:

- to indirectly earth at least one point (36, 38) in each phase between both ends of the second semiconducting layer (18).

23. A method according to any one of claims 21 - 22, **characterized** in that said method comprises furthermore the step:

- to apply a third semiconducting layer (26) at each said interruption (20) in the second semiconducting layer (18) in order to reduce the amplification of the electric field strength at said interruption (20).

24. A method according to any one of claims 21 - 23, **characterized** in that each said interruption (20) is achieved by removing the second semiconducting layer (18) around the periphery of the high voltage cable (10) down to the first insulating layer (16) so that grooves (20) surrounded by the second semiconducting layer (18) are formed.

25. A method according to claim 24, **characterized** in that the step of applying said means (24, 26) comprises the following steps:

- to apply a second insulating layer (24) over each groove (20) in such a way that part of the second semiconducting layer is (18) on both sides of each groove (20) is additionally covered; and
- to apply a third semiconducting layer (26) on the second insulating layer (24) in such a way that the one end of the third semiconducting layer (26) covers the one edge of the second insulating layer (24) and has electric contact to the second semiconducting layer (18), and the other end of the third semiconducting layer (18) does not cover the other edge of the second insulating layer (24) but extends along a part of the second semiconducting layer (18) located under the second insulating layer (24).

26. A method according to any one of claims 21 - 25, **characterized** in that the step to earth in cross-connected manner comprises the following step:

- to connect the second semiconducting layer of the different phases (1, 2, 3) at each said interruption (20), and indirectly earthing the aforementioned.

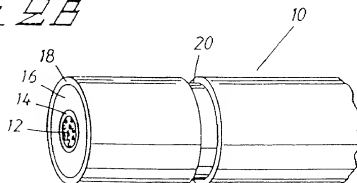
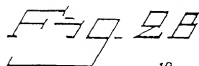
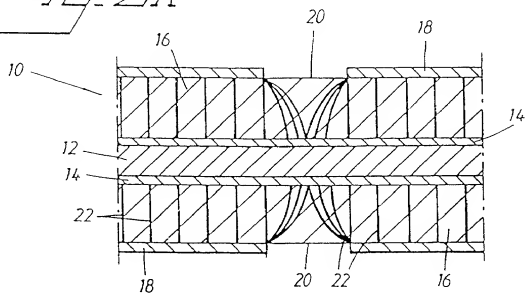
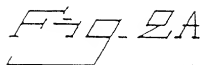
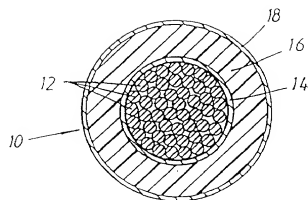
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27. A method according to claim 26, **characterized** in that the step to earth in cross-connected manner comprises furthermore the following steps; whereby the number of interruptions (20_{11} , 20_{12} ; 20_{21} , 20_{22} , 20_{31} , 20_{32}) per phase are $2(n-1)$ and the number of connected sections of the second semiconducting layer (18_{11} , 18_{12} ,

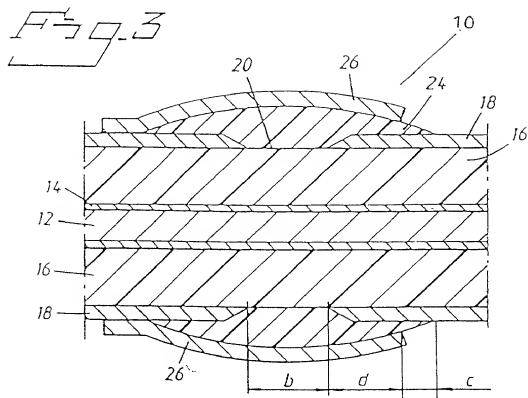
10 18_{13} ; 18_{21} , 18_{22} , 18_{23} ; 18_{31} , 18_{32} , 18_{33}) per phase are $3(n-1)$:

- to connect at interruption (20) number q , where $1 \leq q \leq 2(n-1)$, of the different phases (1, 2, 3), section r , where $1 \leq r \leq 3(n-1)$, of the second semiconducting layer (18) of one phase (1, 2, 3) to section $(r+1)$ of the second semiconducting layer of the consecutive phase;
- 15 • to connect section r of the second semiconducting layer (18) of the first phase (1) to section r of the second semiconducting layer (18) of the remaining phases (2, 3); and
- to connect section r of the second semiconducting layer (18) of the last phase (3) and section $(r+1)$ of the second semiconducting layer (18) of the first phase (1) to the indirect earthing (40), whereby the aforementioned does not apply to section
- 20 r , where r is evenly divisible by 3, except for the last section, i. e. $r=3(n-1)$.

1/6



2/6



3/6

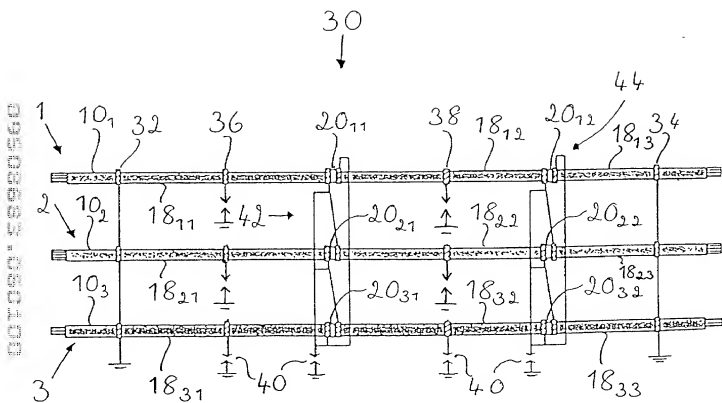


Fig. 4

4/6

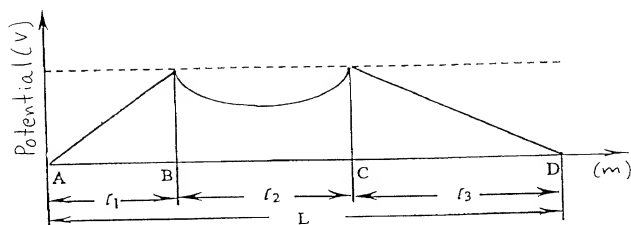


Fig. 5

5/6

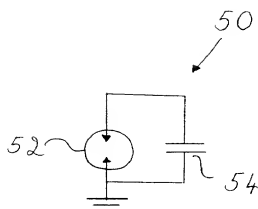


Fig. 6a

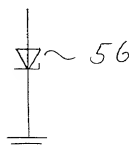


Fig. 6b

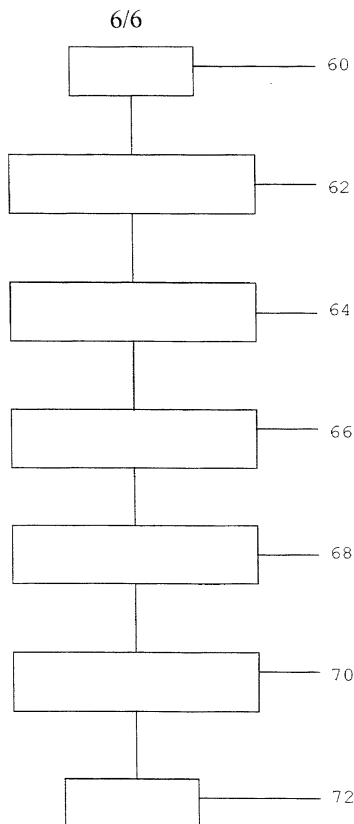


Fig. 7

Declaration, Power Of Attorney and Petition

Page 1 of 3

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

POWER TRANSFORMER/REACTOR AND A METHOD OF ADAPTING A HIGH VOLTAGE
CABLE

the specification of which

☐ is attached hereto.

☒ was filed on 28 March 2000 as

Application Serial No. 09/508,683

and amended on _____.

☒ was filed as PCT international application

Number PCT/SE98/01749

on 29 September 1998,

and was amended under PCT Article 19

on _____ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed
<u>9703563-8</u>	<u>SWEDEN</u>	<u>30 September 1997</u>	<input checked="" type="checkbox"/> Yes <input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes <input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes <input type="checkbox"/> No
_____	_____	_____	<input type="checkbox"/> Yes <input type="checkbox"/> No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

_____ (Application Number)	_____ (Filing Date)
_____ (Application Number)	_____ (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
PCT/SE98/01749	29 September 1998	
_____	_____	_____
_____	_____	_____

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; Vincent J. Sunderdick, Reg. No. 29,004; William E. Beaumont, Reg. No. 30,996; Robert F. Gnuse, Reg. No. 27,295; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Robert W. Hahl, Reg. No. 33,893; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; Paul E. Rauch, Reg. No. 38,591; William T. Enos, Reg. No. 33,128; and Michael E. McCabe, Jr., Reg. No. 37,182; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, MCCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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